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AN ANALYSIS TO DETERMINE THE FEASIBILITY OF A NON-LUMINOUS PYROTECHNIC FUMER

Walter J. Puchalski

Frankford Arsenal
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Results of a mathematical analysis of the thermal radiation emitted from pyrotechnic compositions in the 5.56 mm to 30 mm family of ammunition indicate that non-luminous, base drag-reducing fumers are not feasible. The major conclusion reached is that no developmental effort on non-luminous, pyrotechnic fumer ammunition should be initiated.

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GLOSSARY

SYMBOL	UNIT	TERM
m	Meter	Length
nm	Nanometer	Wavelength
w	Watt	Power
E_t	Lumen/m^2	Threshold Illumination Value
I_v	Lumen/Stearadian	Luminous Intensity
R	m	Distance from Source to Observer
T	Degrees K	Temperature
λ	nm	Wavelength
$m_e(\lambda)$	w/m^2	Radiant Emittance at Wavelength, λ
m_e	w/m^2	Total Radiant Emittance Between λ_1 and λ_2
σ	w/T^4-m^2	Boltzmann Constant
Φ_E	w	Radiant Flux
A	m^2	Area of Source
Φ_v	Lumen	Luminous Flux
L_v	Lumen/Stearadian-m^2	Luminance
m_v	Lumen/m^2	Luminous Emittance
D	m	Diameter of Radiator
a	--	Absorptance
K	Lumen-m^2/w	Caliber Constant
C_1	w-nm^{-4}/m^2	Planck Equation Constant
C_2	nm-T	Planck Equation Constant

INTRODUCTION

For the past 50 years tracer ammunition has performed well in its assigned role of fire control assistance. This role is of paramount importance to the gunner, for without it there would be no easy means of directing modern, rapid-fire weapons without an inordinate waste of ammunition and possibly lives. In addition to fire control, tracers have also been shown to have a decided psychological effect both on the enemy (a burst of lights coming towards him) and on the gunner (a clear indication of his effective firepower).

Ancillary to these roles, tracers have been performing in a generally overlooked capacity, that of base drag reduction. Because each round to date has employed a pyrotechnic to reduce its base drag, the question arises as to the feasibility of developing a pyrotechnic fumer composition which has good base drag-reducing characteristics but does not have a visible signature. It is the purpose of this report to determine that feasibility.

ANALYSIS

Perception of a tracer/fumer round by either the gunner, friendly troops, or the enemy depends primarily upon the overall illumination of the background against which the round is observed. In order to develop an invisible pyrotechnic fumer one must select a pyrotechnic reaction which does not emit visible light exceeding the "threshold illumination". Threshold illumination is defined as that minimum level of light which can be perceived by the eye.

In Table I, values of threshold illumination are given for both night and day "average" conditions for various colored flames[1].

Table I. Threshold Illumination (E_t)* Values

Color of Flame	E_t(Night)	E_t(Day)
Red	0.8×10^{-6}	0.5×10^{-3}
Green	1.2×10^{-6}	0.9×10^{-3}
Yellow	2.0×10^{-6}	1.0×10^{-3}
White	3.0×10^{-6}	1.5×10^{-3}

*See list of symbols.

It is readily seen that as expected, the threshold illumination is much lower at night than during the day, and the same source is five hundred to one thousand times easier to see at night than during the day.

[1]A. A. Shidlovsky, "Fundamentals of Pyrotechnics", Picatinny Technical Memorandum 1615 (1965).

To meet an invisible fumer requirement, therefore, the pyrotechnic reaction must be such that it emits a light level below the threshold illumination value of a white flame at night. Because this study is based on thermal radiation alone, a <u>specific</u> color emitter is unattainable. Therefore, white light is used as a representative color. Also night conditions are used since this affords an optimum probability for visibility. It can be seen that these assumptions produce the easiest conditions for visibility and if these are exceeded then the projectile cannot be considered invisible. Since perception first occurs at a light level equal to the threshold illuminance, then the minimum intensity (I_V) of a flame needed for observation at a distance (R) is given by the relationship:

$$I_V = E_t R^2 \tag{1}$$

A plot of this relationship for a white flame under night conditions is given Figure 1. The problem is now to calculate the theoretical luminous emittance of source[2]. To do this the following assumptions are made:

1. Only thermal radiation will be considered. No spectral emission will be considered.
2. Pyrotechnic flame absorptance (a) is 0.80. The flame is not a perfect blackbody (BB) but an almost blackbody (ABB) with a generally accepted value of 80% BB.
3. Pyrotechnic flames are adiabatic. No heat is lost to the surroundings.
4. The fumer flame has the same diameter as the projectile in which it is employed.

A source at temperature, T, and wavelength λ, has a radiant emittance $M_e(\lambda)$, given by the Planck equation:

$$M_e(\lambda) = aC_1\lambda^{-5}/(\exp(C_2/\lambda T)-1) \tag{2}$$

The total radiant emittance, M_e, can be found by integrating equation (2) from $\lambda = 0$ to $\lambda = \infty$

$$Me = \int_0^\infty Me(\lambda)\,d\lambda = a\sigma T^4 \tag{3}$$

This is the Stefan-Boltzmann equation (modified for ABB) where σ is the Stefan-Boltzmann constant.

For an ABB radiator of area A, the radiant flux Φ_e, is

$$\Phi_e = Aa\sigma T^4 \tag{4}$$

Where Φ_e and A are in watts and meter^2, respectively.

The total radiant flux is not the sole criterion for visibility. One must also consider how this flux is distributed over the visible

[2]<u>Optics</u>, M. V. Klein, p 121-9, John Wiley & Sons, NY (1970), Derivation of equations based on cited reference.

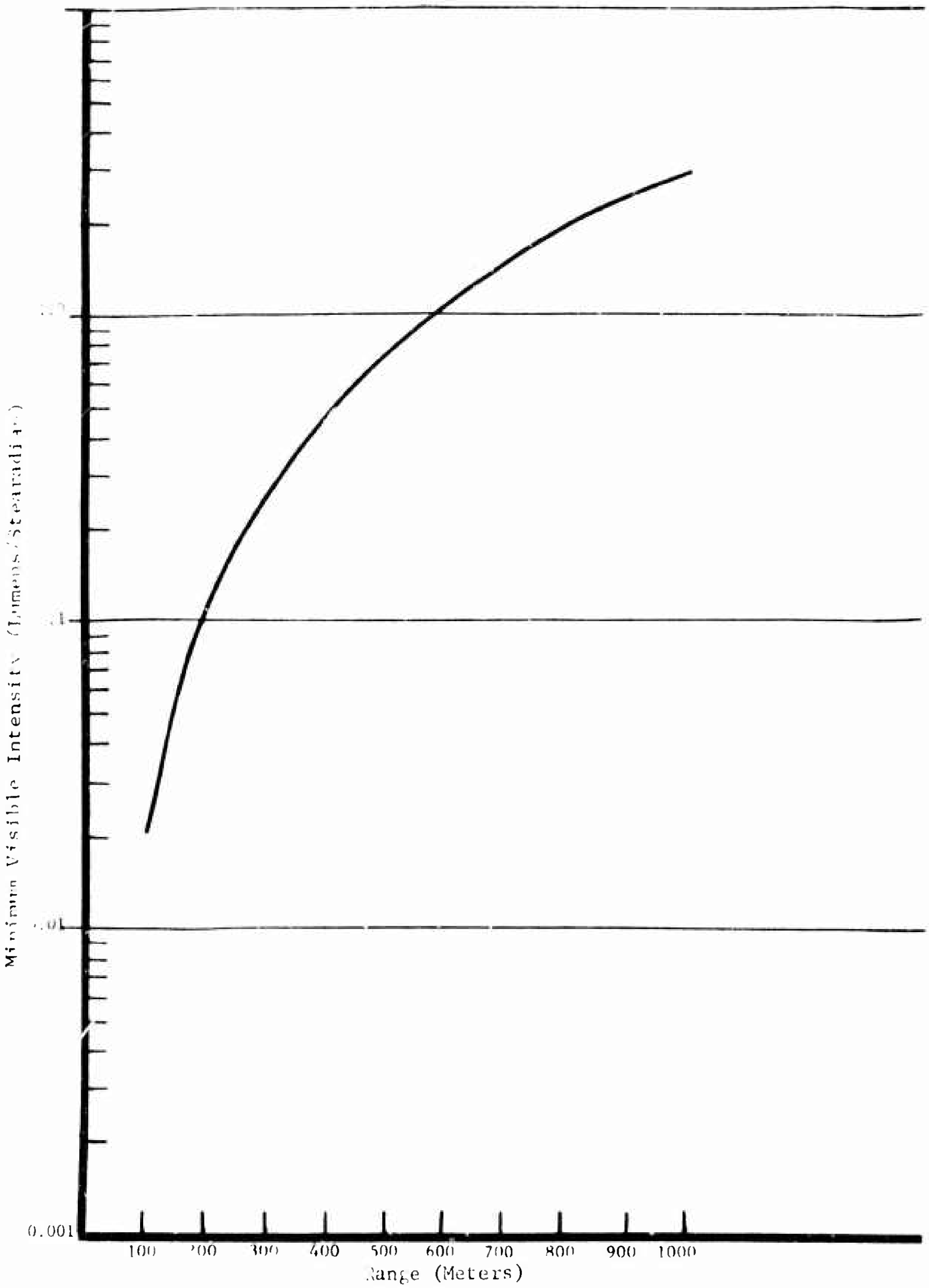

Figure 1. Minimum Visible Intensity vs. Range for White Light at Night

portion of the spectrum. Radiant flux is called luminous flux when evaluated in the visible spectrum as to its capacity to evoke the sensation of light in a human observer.

To calculate the luminous flux, Φ_v, we must first introduce a new factor, the standard luminosity curve (y_λ). This curve[3] is the result of numerous psychophysical experiments to determine the wavelength of maximum response of the "average eye". Those experiments have determined that the wavelength of maximum response of the human eye is 555 nm and also correlates this λ with a <u>luminous flux</u> of 680 lumens for each watt of radiant flux. At all other λ's, the response of the eye is less than 680 lumens/watt. (Figure 2, Table II). This standard luminosity curve when multiplied by the radiant flux yields the energy distribution proportional to that perceived by the human eye. To find the exact luminous flux the energy distribution is multiplied by 680 lumen/watt. Mathematically,

$$\Phi_v = 680 \int_0^\infty y_\lambda \Phi_e(\lambda)\, d\lambda \qquad (5)$$

Now, if the luminous intensity of the source (I_v) is related to the luminance (L_v) below as

$$I_v = AL_v \qquad (6)$$

and L_v to the luminous emittance (M_v) as

$$L_v = \frac{M_v}{\pi} \qquad (7)$$

then

$$I_v = A\frac{M_v}{\pi} \qquad (8)$$

But in the visible region of the spectrum $M_e = M_v$. Therefore,

$$I_v = A\frac{M_e}{\pi} \qquad (9)$$

But it is also true that

$$\Phi_v = AM_e \qquad (10)$$

Therefore

$$I_v = \frac{\Phi_v}{\pi} \qquad (11)$$

and substituting (5) into (11) yields

$$I_v = \frac{680}{\pi} A \int_0^\infty y_\lambda\, aC_1 \lambda^{-5}/(\exp(C_2/\lambda T)-1)\, d\lambda \qquad (12)$$

and if the source is a circular radiator with diameter, D, then

$$A = \pi D^2/4 \qquad (13)$$

and

$$I_v = K \int_0^\infty y_\lambda\, aC_1 \lambda^{-5}/(\exp(C_2/\lambda T)-1)\, d\lambda \qquad (14)$$

where

$$K = \frac{680D^2}{4} \qquad (15)$$

[3] A. C. Hardy, Ed., Handbook of Colorimetry, M.I.T. Technology Press, Cambridge, MA, 1936

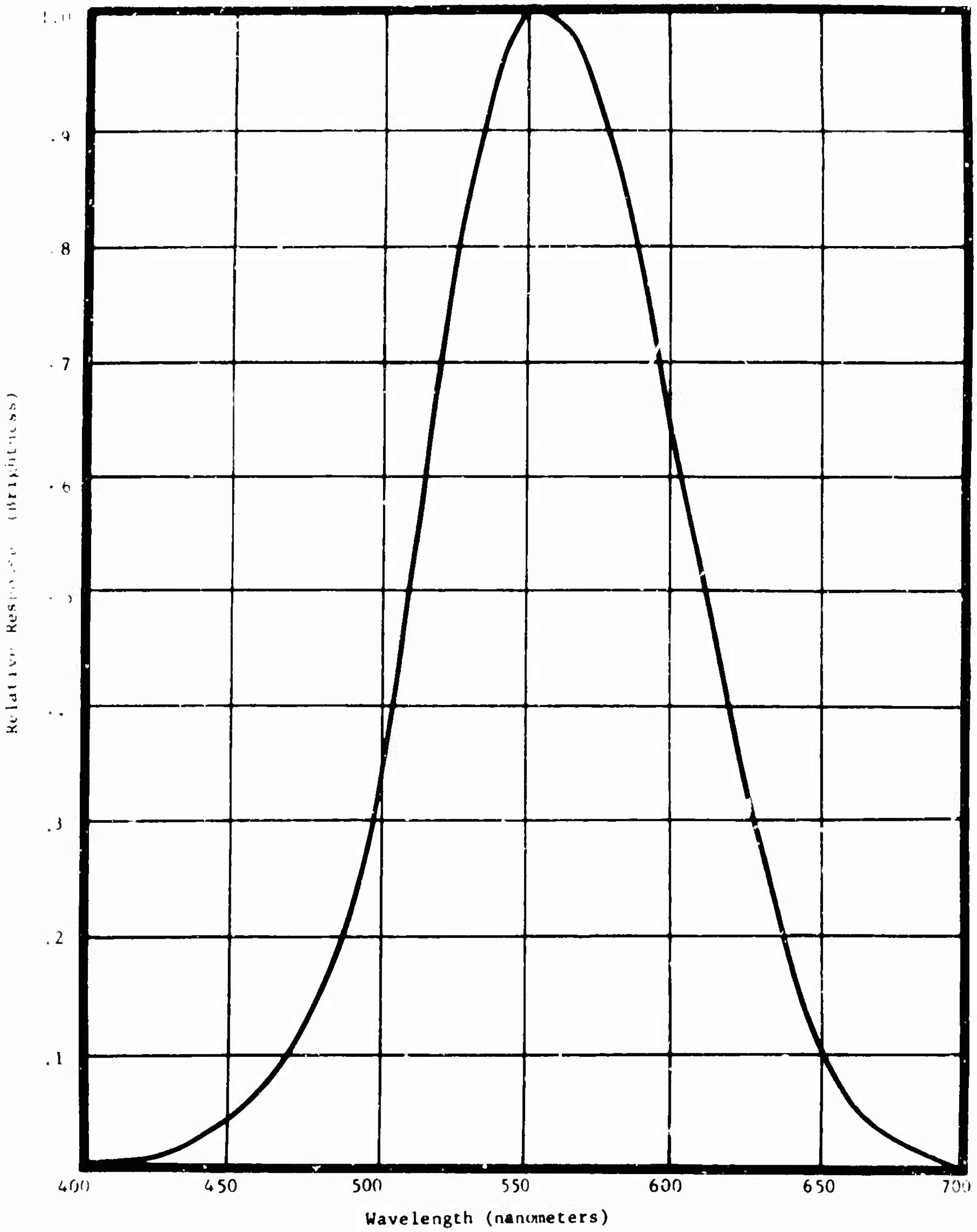

Figure 2. Spectral Response Curve for a "Normal" Eye

TABLE II. Standard Visibility Function

λ	0	1	2	3	4	5	6	7	8	9
0.38μ	40×10^{-6}	45	49	54	59	64	71	80	90	104
0.39	120×10^{-6}	138	155	173	193	215	241	272	308	350
0.40	40×10^{-5}	45	49	54	59	64	71	80	90	104
0.41	120×10^{-5}	138	156	174	195	218	244	274	310	352
0.42	400×10^{-5}	455	515	581	651	726	806	889	976	1066
0.43	0.01160	1257	1358	1463	1571	1684	1800	1920	2043	2170
0.44	0.02300	2430	2570	2700	2840	2980	3130	3290	3450	3620
0.45	0.03800	3990	4180	4380	4590	4800	5020	5250	5490	5740
0.46	0.06000	6270	6540	6810	7090	7390	7690	8020	8360	8720
0.47	0.0910	950	992	1035	1080	1126	1175	1225	1278	1333
0.48	0.1390	1448	1507	1567	1629	1693	1761	1833	1909	1991
0.49	0.2080	2173	2270	2371	2476	2586	2701	2823	2951	3087
0.50	0.3230	3382	3544	3714	3890	4073	4259	4450	4642	4836
0.51	0.5030	5229	5436	5648	5865	6082	6299	6511	6717	6914
0.52	0.7100	7277	7449	7615	7776	7932	8082	8225	8363	8495
0.53	0.8620	8739	8851	8956	9056	9149	9238	9320	9393	9471
0.54	0.9540	9604	9661	9713	9760	9803	9840	9873	9902	9928
0.55	0.9950	9969	9983	9994	1.0000	1.0002	1.0001	9995	9984	9969
0.56	0.9950	9926	9898	9865	9828	9786	9741	9691	9638	9581
0.57	0.9320	9455	9386	9312	9235	9154	9069	8981	8890	8796
0.58	0.8700	8600	8496	8388	8277	8163	8046	7928	7809	7690
0.59	0.7570	7449	7327	7202	7076	6949	6822	6694	6565	6437
0.60	0.6310	6182	6054	5926	5797	5668	5539	5410	5282	5156
0.61	0.5030	4905	4781	4658	4535	4412	4291	4170	4049	3929
0.62	0.3810	3690	3570	3449	3329	3210	3092	2977	2864	2755
0.63	0.2650	2548	2450	2354	2261	2170	2082	1996	1912	1830
0.64	0.1750	1672	1596	1523	1452	1382	1316	1251	1188	1128
0.65	0.1070	1014	961	910	862	816	771	729	688	648
0.66	0.0610	574	539	506	475	446	418	391	366	343
0.67	0.0320	299	280	263	247	232	219	206	194	182
0.68	1700×10^{-5}	1585	1477	1376	1281	1192	1108	1030	956	886
0.69	820×10^{-5}	759	705	656	612	572	536	503	471	440
0.70	410×10^{-5}	381	355	332	310	291	273	256	241	225
0.71	2100×10^{-6}	1954	1821	1699	1587	1483	1387	1297	1212	1130
0.72	1050×10^{-6}	975	907	845	788	736	688	644	601	560
0.73	520×10^{-6}	482	447	415	387	360	335	313	291	270
0.74	250×10^{-6}	231	214	198	185	172	160	149	139	130
0.75	120×10^{-6}	111	103	96	90	84	78	74	69	64
0.76	60×10^{-6}	56	52	48	45	42	39	37	35	32
0.77	30×10^{-6}									

Having developed equation (14) from basic radiation laws, this equation can be applied to pyrotechnic flames in general and to fumer flames in particular. This is done by substituting the reaction flame temperature in the temperature parameter and the diameter of the projectile in which the fumer is employed in the K-value. K-values for various diameters (calibers) are given in Table III below.

TABLE III. K Values for Small-Arms Ammunition

Caliber(mm)	K
5.56	52.6×10^{-4}
6.00	61.2×10^{-4}
7.62	98.7×10^{-4}
20	68.0×10^{-3}
30	15.3×10^{-2}

It can be deduced from Table III that, as the projectile increases in diameter, it becomes more difficult to not see the pyrotechnic flame.

Evaluating equation (14) between the λ limits of 380-720 mm (visible region of the spectrum) for temperatures between 300K and 5700K (reaction temperature limits) with each of the above K-values (diameters) and solving for R in equation (1), yields the maximum range to which each projectile is visible (Tables IV-VIII).

DISCUSSION

In a recent report[4], it is concluded that high reaction temperature fumer mixes produce better base drag reduction than low reaction temperature mixes. Using the data in Table A-III of that report, it is seen that a fumer mix (F-5) with a measured flame temperature[5] of 1000K gave only a 6.2% reduction in overall drag, whereas the high (>3300K) temperature fumer (F-4) reduced drag 22.8%. The lower temperature fumer mix is the same composition developed for the XM-276, 7.62 mm dim tracer and emits no visible light when viewed at night. Using this mix as a representative "invisible fumer" and the higher flame temperature mix as a representative fumer, Table IX lists the maximum visible range for various calibers.

[4]Kwatnoski, R., "Drag Reducing Fumer for Application in Small Arms Ammunition", Frankford Arsenal Report R-3003, March, 1974.
[5]Arnold, C. B., Carrara, C., Larocca, A. J., "Radiation Measurement of Burning Chemical Mixtures", Frankford Arsenal Report R-1957, February 1970.

TABLE IV. Luminosity and Maximum Visible Range versus Temperature for 5.56mm Projectile

THERMAL RADIATION IN THE 380-720 NANOMETER RANGE.

--V L-F (LUMEN-S.. 4/WATT)	TEMPERATURE (K)	LUMINOUS INTENSITY (LUMEN/STERADIAN)	MAX VISIBLE RANGE (METERS)
32.0E-04			
	300.	37.7E-28	.00
	400.	15.7E-20	.00
	500.	77.0E-16	.00
	600.	12.2E-12	.00
	700.	25.9E-10	.03
	800.	15.3E-08	.23
	900.	38.2E-07	1.13
	1000.	51.5E-06	[illegible]
	1100.	44.1E-05	12.12
	1200.	26.8E-04	24.88
	1300.	12.5E-03	[illegible]
	1400.	47.0E-03	[illegible]
	1500.	14.9E-02	222.98
	1600.	41.2E-02	370.64
	1700.	10.1E-01	541.49
	1800.	22.7E-01	869.15
	1900.	46.6E-01	1246.94
	2000.	89.5E-01	1727.38
	2100.	16.2E+00	2321.89
	2200.	27.7E+00	3040.48
	2300.	45.4E+00	3891.68
	2400.	71.5E+00	4882.41
	2500.	10.9E+01	6018.01
	2600.	16.0E+01	7302.30
	2700.	22.9E+01	8737.65
	2800.	32.0E+01	10325.12
	2900.	43.7E+01	12064.56
	3000.	58.4E+01	13954.79
	3100.	76.7E+01	15993.68
	3200.	99.4E+01	18178.33
	3300.	12.6E+02	20505.17
	3400.	15.8E+02	22970.08
	3500.	19.6E+02	25568.52
	3600.	24.0E+02	28295.58
	3700.	29.1E+02	31148.12
	3800.	34.9E+02	34114.80
	3900.	41.5E+02	37196.18
	4000.	48.9E+02	40384.76
	4100.	57.2E+02	43675.02
	4200.	66.4E+02	47061.49
	4300.	76.6E+02	50538.75
	4400.	87.8E+02	54101.50
	4500.	10.0E+03	57744.53
	4600.	11.3E+03	61452.79
	4700.	12.8E+03	65251.38
	4800.	14.3E+03	69105.55
	4900.	16.0E+03	73020.74
	5000.	17.8E+03	76992.54
	5100.	19.7E+03	81016.75
	5200.	21.7E+03	85089.32
	5300.	23.9E+03	89206.40
	5400.	26.2E+03	93364.32
	5500.	28.6E+03	97559.57
	5600.	31.1E+03	101788.82
	5700.	33.7E+03	106048.91

TABLE V. Luminosity and Maximum Visible Range versus Temperature for 6mm Projectile

THERMAL RADIATION IN THE 380-720 NANOMETER RANGE.

K-VALUE (LUMEN-SEC. M/WATT)
91.2E- 4

TEMPERATURE (K)	LUMINOUS INTENSITY (LUMEN/STERADIAN)	MAX VISIBLE RANGE (METERS)
300.	43.9E-28	.00
400.	18.2E-21	.00
500.	89.5E-16	.00
600.	14.1E-12	.00
700.	30.1E-10	.03
800.	17.8E-08	.24
900.	44.4E-07	1.22
1000.	59.9E-06	4.47
1100.	51.3E-05	13.08
1200.	31.2E-04	32.23
1300.	14.5E-03	69.53
1400.	54.6E-03	134.95
1500.	17.4E-02	240.52
1600.	48.0E-02	399.79
1700.	11.8E-01	627.23
1800.	26.4E-01	937.52
1900.	54.3E-01	1345.02
2000.	10.4E+00	1863.25
2100.	18.8E+00	2504.52
2200.	32.3E+00	3279.63
2300.	52.9E+00	4197.79
2400.	83.2E+00	5266.44
2500.	12.6E+01	6491.36
2600.	18.6E+01	7876.66
2700.	26.6E+01	9424.91
2800.	37.2E+01	11137.25
2900.	50.8E+01	13013.51
3000.	68.0E+01	15052.41
3100.	89.3E+01	17251.68
3200.	11.5E+02	19608.16
3300.	14.7E+02	22118.02
3400.	18.4E+02	24776.81
3500.	22.8E+02	27579.63
3600.	27.9E+02	30521.19
3700.	33.9E+02	33595.94
3800.	40.6E+02	36798.12
3900.	48.3E+02	40121.87
4000.	56.9E+02	43561.25
4100.	66.6E+02	47110.31
4200.	77.3E+02	50763.14
4300.	89.2E+02	54513.91
4400.	10.2E+03	58356.89
4500.	11.6E+03	62285.47
4600.	13.2E+03	66297.19
4700.	14.9E+03	70383.78
4800.	16.7E+03	74541.10
4900.	18.6E+03	78764.24
5000.	20.7E+03	83048.44
5100.	22.9E+03	87389.18
5200.	25.3E+03	91782.08
5300.	27.8E+03	96222.99
5400.	30.4E+03	100707.96
5500.	33.2E+03	105233.14
5600.	36.2E+03	109795.09
5700.	39.3E+03	114390.26

TABLE VI. Luminosity and Maximum Visible Range versus Temperature for 7.62mm Projectile

THERMAL RADIATION IN THE 380-720 NANOMETER RANGE.

[illegible] (LUMENS / WATT) 46.7[illegible]

TEMPERATURE (K)	LUMINOUS INTENSITY (LUMEN/STERADIAN)	MAX VISIBLE RANGE (METERS)
300.	71.8E-28	.00
400.	24.4E-20	.00
500.	14.4E-15	.00
600.	22.8E-12	.00
700.	48.5E-10	.04
800.	29.8E-08	.31
900.	71.7E-07	1.55
1000.	96.6E-06	5.67
1100.	82.7E-05	16.61
1200.	50.3E-04	40.93
1300.	23.4E-03	88.30
1400.	88.1E-03	171.38
1500.	28.0E-02	305.45
1600.	77.3E-02	507.71
1700.	19.0E-01	796.54
1800.	42.5E-01	1190.59
1900.	87.5E-01	1708.09
2000.	16.8E+00	2366.22
2100.	30.3E+00	3180.58
2200.	52.0E+00	4164.94
2300.	85.3E+00	5330.93
2400.	13.4E+01	6688.06
2500.	20.4E+01	8243.63
2600.	30.0E+01	10002.88
2700.	43.0E+01	11969.07
2800.	60.0E+01	14143.62
2900.	81.9E+01	16526.36
3000.	11.0E+02	19115.65
3100.	14.4E+02	21908.58
3200.	18.6E+02	24901.17
3300.	23.7E+02	28088.53
3400.	29.7E+02	31465.04
3500.	36.8E+02	35024.44
3600.	45.1E+02	38760.05
3700.	54.6E+02	42664.79
3800.	65.5E+02	46731.37
3900.	77.9E+02	50952.33
4000.	91.8E+02	55320.13
4100.	10.7E+03	59827.22
4200.	12.5E+03	64466.09
4300.	14.4E+03	69229.34
4400.	16.5E+03	74109.69
4500.	18.8E+03	79100.01
4600.	21.3E+03	84193.39
4700.	24.0E+03	89383.10
4800.	26.9E+03	94662.65
4900.	30.0E+03	100025.78
5000.	33.4E+03	105466.46
5100.	36.9E+03	110978.92
5200.	40.8E+03	116557.64
5300.	44.8E+03	122197.33
5400.	49.1E+03	127892.96
5500.	53.6E+03	133639.73
5600.	58.3E+03	139433.07
5700.	63.3E+03	145268.66

TABLE VII. Luminosity and Maximum Visible Range versus Temperature for 20mm Projectile

THERMAL RADIATION IN THE 380-720 NANOMETER RANGE.

[illegible] (LUMEN-S.. M/WATT) [illegible]

TEMPERATURE (K)	LUMINOUS INTENSITY (LUMEN/STERADIAN)	MAX VISIBLE RANGE (METERS)
300.	48.8E-27	.00
400.	20.3E-19	.00
500.	99.5E-15	.00
600.	15.7E-11	.01
700.	33.4E-09	.11
800.	19.8E-07	.81
900.	49.4E-06	4.06
1000.	66.5E-05	14.89
1100.	57.0E-04	43.59
1200.	34.6E-03	107.44
1300.	16.1E-02	231.78
1400.	60.7E-02	449.84
1500.	19.3E-01	801.73
1600.	53.3E-01	1332.65
1700.	13.1E+00	2090.76
1800.	29.3E+00	3125.06
1900.	60.3E+00	4483.40
2000.	11.6E+01	6210.84
2100.	20.9E+01	8348.39
2200.	35.9E+01	10932.12
2300.	58.7E+01	13992.62
2400.	92.5E+01	17554.80
2500.	14.0E+02	21637.87
2600.	20.7E+02	26255.55
2700.	29.6E+02	31416.38
2800.	41.3E+02	37124.15
2900.	56.5E+02	43378.36
3000.	75.5E+02	50174.71
3100.	99.2E+02	57505.59
3200.	12.8E+03	65360.53
3300.	16.3E+03	73726.72
3400.	20.5E+03	82589.37
3500.	25.4E+03	91932.09
3600.	31.1E+03	101737.30
3700.	37.6E+03	111986.46
3800.	45.1E+03	122660.42
3900.	53.7E+03	133739.58
4000.	63.3E+03	145204.17
4100.	74.0E+03	157034.36
4200.	85.9E+03	169210.47
4300.	99.1E+03	181713.04
4400.	11.4E+04	194522.96
4500.	12.9E+04	207621.56
4600.	14.7E+04	220990.64
4700.	16.5E+04	234612.58
4800.	18.5E+04	248470.33
4900.	20.7E+04	262547.46
5000.	23.0E+04	276828.15
5100.	25.5E+04	291297.25
5200.	28.1E+04	305940.26
5300.	30.9E+04	320743.31
5400.	33.8E+04	335693.18
5500.	36.9E+04	350777.28
5600.	40.2E+04	365983.64
5700.	43.6E+04	381300.87

TABLE VIII. Luminosity and Maximum Visible Range versus Temperature for 30mm Projectile

THERMAL RADIATION IN THE 380-720 NANOMETER RANGE.

K-VALUE (LUMEN-S., W/WATT) 15.3E-2

TEMPERATURE (K)	LUMINOUS INTENSITY (LUMEN/STERADIAN)	MAX VISIBLE RANGE (METERS)
300.	11.6E-26	.00
400.	45.6E-19	.00
500.	22.4E-14	.00
600.	35.4E-11	.01
700.	75.2E-09	.16
800.	44.6E-07	1.22
900.	11.1E-05	6.09
1000.	15.0E-04	22.34
1100.	12.8E-03	65.38
1200.	77.9E-03	161.16
1300.	36.3E-02	347.67
1400.	13.7E-01	674.76
1500.	43.4E-01	1202.60
1600.	12.0E+00	1998.97
1700.	29.5E+00	3136.14
1800.	65.9E+00	4687.59
1900.	13.6E+01	6725.10
2000.	26.0E+01	9315.26
2100.	47.0E+01	12522.59
2200.	80.7E+01	16394.17
2300.	13.2E+02	20988.93
2400.	20.8E+02	26332.20
2500.	31.6E+02	32456.80
2600.	46.5E+02	39383.32
2700.	66.6E+02	47124.57
2800.	93.0E+02	55686.23
2900.	12.7E+03	65067.55
3000.	17.0E+03	75262.07
3100.	22.3E+03	86258.38
3200.	28.8E+03	98040.80
3300.	36.7E+03	110590.09
3400.	46.0E+03	123884.05
3500.	57.0E+03	137898.14
3600.	69.9E+03	152605.94
3700.	84.7E+03	167979.69
3800.	10.2E+04	183990.62
3900.	12.1E+04	200609.37
4000.	14.2E+04	217806.25
4100.	16.6E+04	235551.55
4200.	19.3E+04	253815.71
4300.	22.3E+04	272569.56
4400.	25.5E+04	291784.44
4500.	29.1E+04	311432.33
4600.	33.0E+04	331485.96
4700.	37.2E+04	351918.88
4800.	41.7E+04	372705.50
4900.	46.5E+04	393821.18
5000.	51.7E+04	415242.22
5100.	57.3E+04	436945.88
5200.	63.2E+04	458910.40
5300.	69.[illegible]E+04	481114.97
5400.	76.1E+04	503539.78
5500.	83.1E+04	526165.92
5600.	90.4E+04	548975.45
5700.	98.1E+04	571951.31

TABLE IX. Maximum Visible Range for Selected Calibers at Temperatures of 1000K and 3000K

Caliber (mm)	Max. Visible Range at 1000K (Meters)	Max. Visible Range at 3000K (Meters)
5.56	4	14,000
6.00	4	15,000
7.62	6	19,000
20	15	50,000
30	22	75,000

From these data it can be seen that thermal radiators are, for all practical purposes, invisible up to a temperature of 1000K. Above this temperature, visible range increases dramatically to where the visible range of the projectile far exceeds the effective range of the projectile. It appears, therefore, that if a non-luminous pyrotechnic fumer were to be employed that it would tend to have a flame temperature near 1000K.

In this analysis, the feasibility of a non-luminous pyrotechnic fumer was based purely on the ABB radiative properties of the fumer mixture flame. Objections can be made to the validity of these properties, but it is felt that this analysis is the least stringent. In this study, no consideration was given to the fumer plume expanding and reacting in air behind the bullet. This would at least double the value of (D) in equation (15) and thereby quadruple the effective radiative surface, thus quadrupling the maximum visible range.

Another criticism can be an unrealistic value of 0.80 for the absorptance (or emissivity) of the flame and the neglect of attenuation due to the atmosphere. However, if the data in Table IX are examined for the 7.62 mm case, the combined effect of attenuation and of too high an absorptance value would have to reduce the 19,000 m value by a factor of 200 to make the round invisible at 100 meters.

CONCLUSIONS

1. Small arms ammunition in the 5.56 mm to 30 mm range, employing a burning pyrotechnic with a reaction temperature of 1000K or less will be practically invisible at night.

2. The larger the diameter of the pyrotechnic cavity of a projectile, the easier it becomes to see the pyrotechnic flame.

3. Since it has been shown that a high reaction temperature is necessary for a good fumer, the probability of a developmental success of a non-luminous pyrotechnic fumer is practically nil.

RECOMMENDATION

The investigation into the development of a non-luminous pyrotechnic fumer, or the requirement of such a round should be discontinued.